Exploring futures from an energy perspective

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SUMMARY

The aim of this thesis is to construct an ECCO-type model of the Netherlands. (the ECCO acronym stands for Enhancement of Capital Creation Options). The purpose of this ECCO model is to explore the long-term consequences of contemporary economic growth patterns and to evaluate alternative strategies for guiding the economy towards a more sustainable state from a energy perspective. The notion that the production of goods and services feeds on a continuous flow of material resources and energy from the physical environment to society is at the base of the ECCO paradigm. Therefore, in ECCO the physical throughput of matter and energy is measured in terms of the amount of primary energy expended in the subsequent stages of production. The incorporation of energy as a metric is considered as a central means for clarifying the interrelationship between societal metabolism and environmental metabolism. The use of the energy unit of account also underlines the notion that fossil energy cannot be substituted for by human made capital and that efficiency improvements are restricted by the second law of thermodynamics.

The primary motivation for writing this thesis is the recognition that the impact of human activities on the environment leads to a continuous degradation of the natural environment and that the rate at which we conduct our affairs cannot be sustained in the long run without exceeding the carrying capacity of the natural environment. The interaction between economic activity and the quality and sustainability of the surrounding environment has laid the foundations for the concept of sustainable development. Although generally accepted as a guiding principle in development planning there is not much consensus about the implementation of sustainable development because of differences in interpretations. These differences are related to various worldviews concerning the relationship between humankind and nature.

In economics the role of the natural environment and natural resources has been subject to changes since classical economists. Within the classical economic view natural resource scarcity was considered an relevant aspect of economic growth. With the rise of industrialization neoclassical economists increasingly focused more and more on the role of capital and human labour as the main factors of production. Natural resources were only considered in relation to their impact on the market, thereby abandoning a considerable proportion of the 'natural capital'. By portraying the human economy as more or less isolated from the 'outside world' a considerable proportion of the negative impacts of economic activity is placed beyond the scope of mainstream economic analysis. In mainstream economics this led to the idea that societal processes are independent of physical constraints.

However, the emerging awareness of ongoing environmental degradation and the notion that environmental problems are multi-faceted led to the recognition that the mutual relationship between ecological and economic systems is not well covered by any single existing discipline. Since the nineteen sixties a growing number of authors took the (bio)physical basis of human production and consumption processes as a point of departure, moving away from the more narrow neoclassical perspective on economic activity.

In this thesis the physical linkage between human production and consumption processes and the natural environment is regarded as an important aspect of sustainable development. It is argued that all societal processes are conditioned by physical laws. In this study 'sustainable development' refers to the *physical* basis of *economic* development. The underlying paradigm is *'that which is not physically possible cannot be economically possible'* (Slesser, 1990). This restriction excludes ecological issues such as biodiversity conservation although it is obvious that the extraction of physical resources and energy are both directly and indirectly related to a broad range of ecological factors that affect the quality of the natural environment.

The production of goods and services, which is at the base of economic development, requires the input of resources and the dissipation of energy. Opposite to material resources energy can neither be recycled nor substituted and is therefore regarded as the ultimate input into production processes. At present by far the largest proportion of the energy inputs required to sustain and expand economic activity is provided by fossil fuels that are irrevocably lost after being dissipated. The dissipation of fossil energy is by definition unsustainable as world reserves are limited and the combustion of fossil fuels gives rise the emission of greenhouse gasses.

In order to identify the extent to which physical factors constrain a societies' development potential the natural capital accounting (NCA) approach was adopted in this study. ECCO can be characterized is a dynamic NCA model that links the production of human made (i.e. manufactured) capital (HMC) to the natural capital that is required to make such production physically possible. ECCO takes into account the time lags between the time of decision to invest in HMC and that HMC becoming productive. By its nature an ECCO-type model explores the rate at which the industrial, HMC producing sector can expand given any assumptions made.

In order to gain insights in the physical relationships between economic activity and the surrounding environment and to assess the physical development potential of the Netherlands economy an ECCO-type model of the Netherlands has been presented in this study. In this ECCO model essentially two types of physical metabolic flows through the economy are distinguished.

The first flow consists of the direct energy requirements for production and consumption activities. The second flow consists of primary energy embodied in goods and services. Insights in the latter flow are important since direct energy inputs consumed by a given sector are passed on through the system embodied in the output of that sector.

In order to determine the flows of energy through the Netherlands economy in the base year 1985 input-output energy analysis (IOEA) was adopted as a methodology. For the year 1985 the total primary energy embodied in the physical output of the production sectors was calculated to be 3149 PJ of which 1733 PJ (55%) concerned direct energy inputs. The results of the IOEA analysis were also applied to estimate the past primary energy expenditures to build up the capital stock in the Netherlands as present at the beginning of 1985. The cumulated past primary energy expenditures embodied in the total capital stock in 1985 were estimated at about 7300 PJ of which almost 40% was embodied in houses, 23% in services capital, 20% in the industrial capital stock and 10% in the transport capital stock. The remaining 7% was distributed over a number of different categories.

ECCO starts from the notion that both natural capital and human made capital are essential in fulfilling human needs. Production and consumption processes are accompanied by a continuous throughput of matter and energy through the economy. Reduction of this physical throughput is considered as an important ingredient if one aims to reduce the trade-off between human activity and the quality and sustainability of the natural environment. In order to explore the physical feasibility of current growth trends as well as alternative strategies moving towards a more sustainable future two scenarios aiming at reducing the throughput of fossil fuels were tested against a reference scenario. In the reference model it was assumed that the direct energy requirements of the various sectors decrease only as a result of autonomous energy savings measures until 2015 (no additional investments are reserved for energy conservation measures). Furthermore, with respect to the import-export conditions it was assumed that the energy equivalence of the imports should not exceed the energy equivalence of the total exports. Although this import-export condition restricts the economic development potential in the long-run it turned out not to be decisive for the development potential in the upcoming decades. From the reference run it appeared that no physical constraints interfered with the growth of the industrial production until 2050. However, since in the reference run the post-2015 potential of autonomous energy savings was assumed to be zero, the rising energy costs of producing fossil fuels surpassed the declining trend in energy requirements for industrial production after 2015. This resulted in a decline of the industrial efficiency below the 1985 level

around the year 2030, thereby stressing the growth of industrial output from that moment on.

The reference run showed that the efficiency improvement of production processes should at least keep pace with the rising energy costs of producing fossil fuels in order to avoid the economies production system to become increasingly inefficient. In the long term, reducing the economies' dependency on fossil fuels seems the only physically feasible path towards a more sustainable society. The increasing emission of fossil fuels related greenhouse gasses as well as the depletion of a non-renewable natural resource marks the current dependency of fossil fuels as being unsustainable.

Two options to reduce the one-way throughput of fossil fuels through the Netherlands economy were evaluated in broad outlines: a stringent energy conservation program and the large scale introduction of solar energy supply systems. The energy conservation program comprises both autonomous savings and investment-related energy savings. The latter require additional investments in energy conservation capital. The concept of Energy Return On Investments (EROI) was used to relate the energy costs of energy conservation measures to the amount of energy conserved. The high EROI of energy conservation measures calculated in this study suggests the presence of a large energy conservation potential. The energy conservation program not only affects the demand for fossil fuels and the related emission of greenhouse gasses but also reduces the depletion rate of the indigenous natural gas reserves, herewith extending the available transition time by another decade. Clearly, the long-term impact of energy conservation measures strongly depends on the assumptions made with respect to the post-2015 technological innovations. With respect to the introduction of renewable energy sources it was shown that the large scale application of solar energy supply systems is physically and technically possible. However, in contrast to the implementation of energy conservation measures, the introduction of solar energy systems is necessarily surrounded by many difficulties and uncertainties.

From the scenario studies it appeared that efficiency improvements in terms of reduced fuel inputs per unit of output initiated an accelerated growth of economic production. This indirect effect interferes with the aim of reducing the throughput of fossil fuels. This outcome can be considered both encouraging and disappointing. The notion that energy conservation policies in the long run do not restrict the growth of economic production can be interpreted as encouraging. This outcome seems to be at variance with the standard economic argument that economic growth is a primary condition to set up a financial basis for environmentally friendly policies.

At the same time however, it appeared that efficiency-increasing

technological changes alone are not sufficient to reduce the throughput of fossil fuels through the economy. Policies aimed at sustainable development should be guided such, that efficiency-increasing technological progress should dominate throughput-increasing technology. Furthermore, the direction of capital investments should be such, that the scale of economic activity remains within the carrying capacity of the physical environment. Such a qualitative change of the structure of the economy seems to be an elementary aspect of policies aimed at sustainable development. Within the framework of the metabolic modelling methodology, ECCO-type models can be successfully applied to assess the ’hard’ physical constraints imposed upon the changes that are desirable in accomplishing a more sustainable future.